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SUMMARY REPORT

Contract DA-19-129-QM-1693

METALLIZED FABRICS RESEARCH

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I INTRODUCTION

This summary report describes an investigation of various metal-coated fabrics under conditions simulating an exposure to radiant heat energy in the wavelength range of 0.4 micron to 20 microns.

The goal of the program is to furnish data on the parameters controlling the performance of metallized substrates as a heat reflecting component of the Thermalibrium suit. The investigation was conducted by National Research Corporation under Contract DA-19-129-QM-1693 for the HQ QMR&E Command, U. S. Army, Natick, Massachusetts during the period of 30 September 1960, and continuing through 31 January 1961. During the contract period, progress reports have been submitted monthly by National Research Corporation. These monthly progress reports describe the technical progress of the work in detail.

Specimens of twelve Fiberglas fabrics and four synthetic fabrics, together with two samples of perforated plastic film were tested during this program. The Fiberglas fabrics were used for the basic work because of the variety of weaves and existence of an easily standardized cleaning technique. The specimens of Fiberglas fabric tested were seven samples of various construction of the plain weave variety, four crowfoot-satin weaves and one sample of the satin weave. The specimens of synthetic fabrics consisted of three Nylon samples and one Dacron sample. The plastic film specimens consisted of one sample of perforated Mylar and one sample of perforated Saran.

The metallized samples were tested for washfastness, abrasion resistance, degradation of the metallized fabric and for parameters which control the radiant heat flow through the fabric. On the basis of the work performed, it was possible to produce samples having increased resistance to radiant heat flow, and an improved washfastness. The present limiting range on per cent reflectivity lies around 75% and the washfastness was improved from less than one wash cycle to two wash cycles. Parameters affecting the reflectance of metal-coated woven substrates were investigated. These parameters were: coating metal, weave type and weave style, thickness of coating metal, substrate material, and single or multiple coatings on one or both sides of the substrate. A fabric having a high efficiency as a barrier to thermal radiation would have to have the following properties:

(1)	Coating metal:	Silver, Gold or Aluminum
(2)	Weave type:	Plain weave type
(3)	Weave style:	Any style having a very high count of yarns in both warp and fill directions, coupled with less than 2% direct path transmission, would be a suitable substrate for metallizing
(4)	Thickness of Coating Metal:	About 1 microinch. These films should have a resistance of less than 1.75 ohms per square for aluminum and 1.0 for silver
(5)	Coating on one or both sides:	Substrate should be coated on both sides
(6)	Single or multiple layers of coating:	Multiple coatings do not increase the thermal efficiency of the metallized substrate. Therefore, single layers of metal films on both sides of the substrate are sufficient
(7)	Substrate material:	Tests indicate that Nylons perform best among fabrics tested

Furthermore, perforated plastic substrates offer another range of materials which could fulfill the functions of a heat reflective component of the Thermalibrium suit. The reflectivities of these substrates would surpass the value of 80%.

It appears on the basis of the work performed that fabrics having properties specified above are suitable for Thermalibrium suit applications. Perforated plastics and precoated yarns offer the best chance for further improvement.

II EQUIPMENT AND PROCEDURE FOR PREPARATION, EXPOSURE AND TESTING OF THE SAMPLES

The general method of preparation and testing of a chosen specimen consisted of:

a. cleaning the specimen

b. metallizing the specimen

c. exposure of metallized specimen to radiant heat and measurement of energy passed through the sample (thermal "porosity")

d. abrasion of the specimen, the measure of abrasion being the resultant change in the thermal porosity of the abraded sample

e. washfastness, here again the measure of damage due to washing was the change in the thermal porosity of the washed sample

f. test for the change in breaking strength of the fabric as a result of cleaning and metallizing.

Specimen Cleaning Method

The purpose of fabric cleaning is to remove various finishes and diffused plasticisers from the fiber surface. These finishes would otherwise outgas in vacuum and impart undesirable properties to the metallic surface, such as small pinholes and surface discoloration; all of which would tend to increase the effective emissivity of the metallized surface of the fabric.

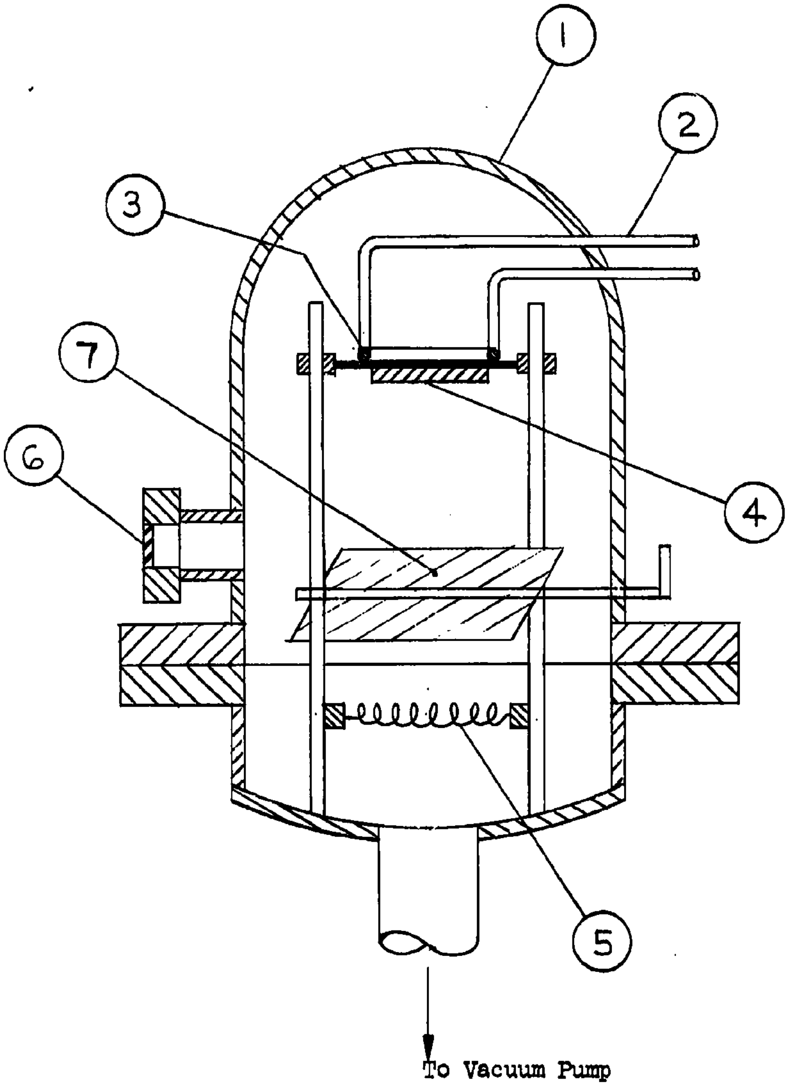
Fiberglas sizing, which mainly consists of starch oil binding and cationic softeners, was removed by heating the fabric to 650-750°F for about two minutes. This heat treatment of Fiberglas fabric, or "coronizing", is commonly used in the textile industry. Mr. John Henry from Exeter Manufacturing Company informed us that when a fabric was heat treated in such a fashion its residual organics content was reduced to the order of 0.06%.

The sizing in the synthetic fabrics was removed chemically. The steps involved in the cleaning procedure were agitation of the fabric in 10% sodium hydroxide for 10 minutes, followed by a thorough rinse with water. The perforated plastics were not cleaned.

Fabric Metallizing

Fabric samples were attached to a water-cooled mounting plate inside the vacuum bell jar. The bell jar was equipped with an evaporative source. Depending upon the type of metal to be deposited, the source was selected from tungsten filaments, and stainless steel or molybdenum boats. The mounting plate was arranged so that it could be vertically moved to various distances from the evaporation source. The separation distance of the sample from the source was about 12 inches for Fiberglas samples and 20 inches for the synthetic fabrics and plastics. Synthetic fibers and plastics were farther removed from the heat source so that they would not be damaged by the heat during the evaporation process. Four glass slides were mounted adjacent to the fabric. A schematic sketch of the coating apparatus is shown in Figure 1.

The bell jar with its contents was evacuated to a blank-off pressure of about 0.05 micron. By moving the vapor shield, the sample was then exposed to metal vapor for various lengths of time not exceeding 10 seconds, depending upon the desired metal film thickness. The thickness of the vacuum-deposited metal film was measured in terms of the resistance of the metal film (ohms per square). The calculated relationship between the thickness of the metal film and the resistance of the metal film is shown in Figure 6.



1	Bell Jar
2	Water Cooling
3	Adjustable Mounting Plate
4	Mounted Fabric
5	Evaporation Source (Filament or Boat)
6	Sight Glass
7	Vapor Shield

Fig. 1. METALLIZING APPARATUS

For vacuum deposition of metal films, four metals of high purity (99.99%) were used. These were: aluminum, which was evaporated from tungsten filaments; gold and silver, which were evaporated from a molybdenum boat-type source, and zinc, which was evaporated from a stainless steel boat-type source. If the separation distance was 20 inches, four tungsten filaments were used, and if the separation distance was 12 inches, six tungsten filaments were used. It is necessary for even coating distribution to evaporate the metal vapor at a normal angle of incidence to the substrate. To accomplish this, more tungsten filaments (six) were installed when the fabric was mounted closer to the evaporation source. In situations where boat-type sources were used, it was found that two boats provided a sufficiently even metal film distribution.

Method and Apparatus for Energy Transmission Measurement

For measuring the flow of thermal energy through the samples, a simple apparatus was constructed. The apparatus shown schematically in Figure 2 consisted of a supply of deaerated water fed to a black-lacquered plate, above which was an infrared heat source. The filament temperature of the source and the flow rate of water was kept constant. The distance separating the source and the receiver was also kept constant. Water temperatures were measured at the inlet and outlet of the receiver plate. After an insertion of a substrate, the temperature drop was observed at the water outlet from the receiver plate. The thermal porosity of the fabric can be expressed as:

$$TP = \frac{(T \text{ outlet} - T \text{ inlet}) \text{ after substrate insertion}}{(T \text{ outlet} - T \text{ inlet}) \text{ before substrate insertion}}$$

The radiant energy arriving at the surface of the substrate is partially reflected, partially transmitted at original wavelength and partially absorbed and reradiated. The TP which is expressed as a fraction of unity

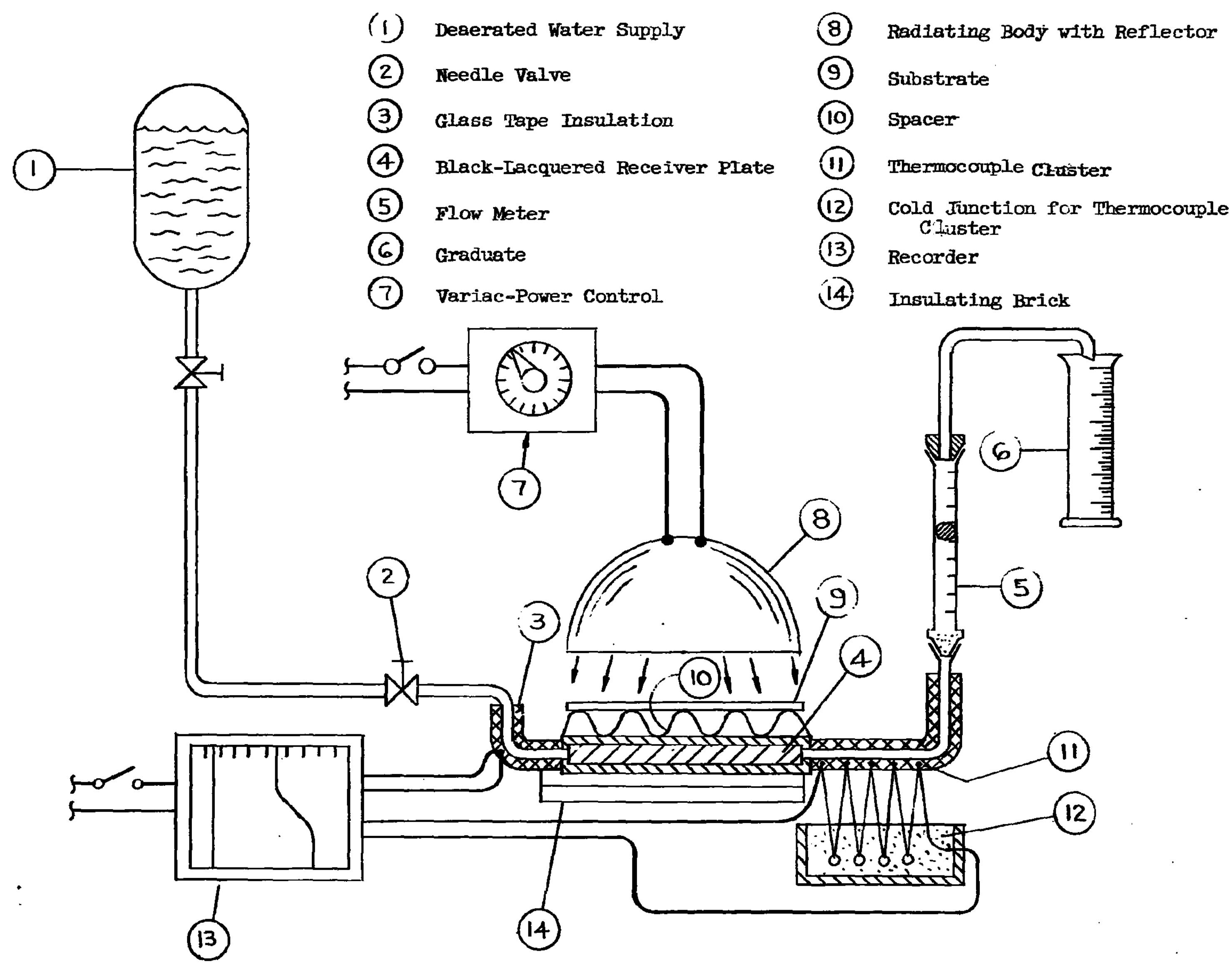


Fig. 2. APPARATUS FOR MEASURING "THERMAL POROSITY"

is then the effective emissivity, plus transmittance at original wavelength, plus a calibration factor. The sum of the above three terms subtracted from unity is then the effective reflectance. The need for a calibration factor probably arises from some of the radiant energy penetrating the glass tape insulation around the thermocouples at the outlet, distorting the reading slightly, and from errors introduced by convection and view factor change when the substrate is introduced. The calibration constant was determined as described under III-C below, for fabric samples with other factors known.

Washfastness, Apparatus and Method of Testing

The apparatus shown in Figure 4 consisted of a tumbling jug, whose dimensions and speed of rotation were identical with Federal Specification CCC-T-191b, Method 5500. The tumbler was filled with 2 litres of water at 120°F. A strong infrared lamp with reflector was focused on the tumbler, thus keeping the water temperature constant at 120°F. Sample or samples were placed in the tumbler along with a ballast fabric. The size of ballast fabrics was identical with that of the sample, and the weight of the sample or samples, plus ballast fabrics, was 500 grams. Five grams of neutral detergent, supplied by HQ QMR&E, U.S. Army in Natick, were placed in the tumbler, which was then rotated for 15 minutes and drained. Two litres of water without detergent were then added to the samples and the tumbler was rotated for an additional five minutes. The total 20 minutes of rotating time was then termed one cycle. A half-cycle consisted of 7 1/2 minutes washing time and 2 1/2 minutes of rinse time. The change in TP of the washed fabric was then used as a measure of damage due to washing.

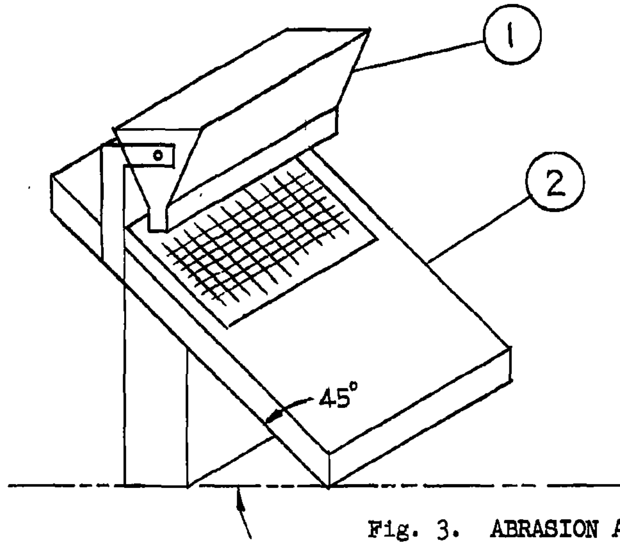
Abrasion Resistance, Method and Apparatus

The conventional testing method consisting of gross removal of material was not applicable, since the films are only 0.5 to 1.2 x 10^{-6} inches thick. Therefore, we built an apparatus shown in Figure 3, consisting of a steel trough from which silica sand or iron grit is allowed to pour over fabric mounted on an inclined plane. The volume of the trough was about 21 cubic inches, and the angle of inclination of the mounting board was 45°. Data showing comparative abrasion resistance as a function of metal coating thickness, were expressed in terms of change in thermal porosity as a function of the number of times exposed to the abrasive.

Testing of Breaking Strength, Method and Apparatus

The method for determining the breaking strength of the woven fabrics is identical with the ravel strip method, Federal Specification CCC-T-191b, Method 5104. The apparatus, however, is different. The method itself consists of preparing a sample of fabric 1 1/4 inches wide if there are more than 50 yarns per inch, or 1 1/2 inches wide, if there are less than 50 yarns per inch. This rectangle of cloth was 6 1/2 inches long.

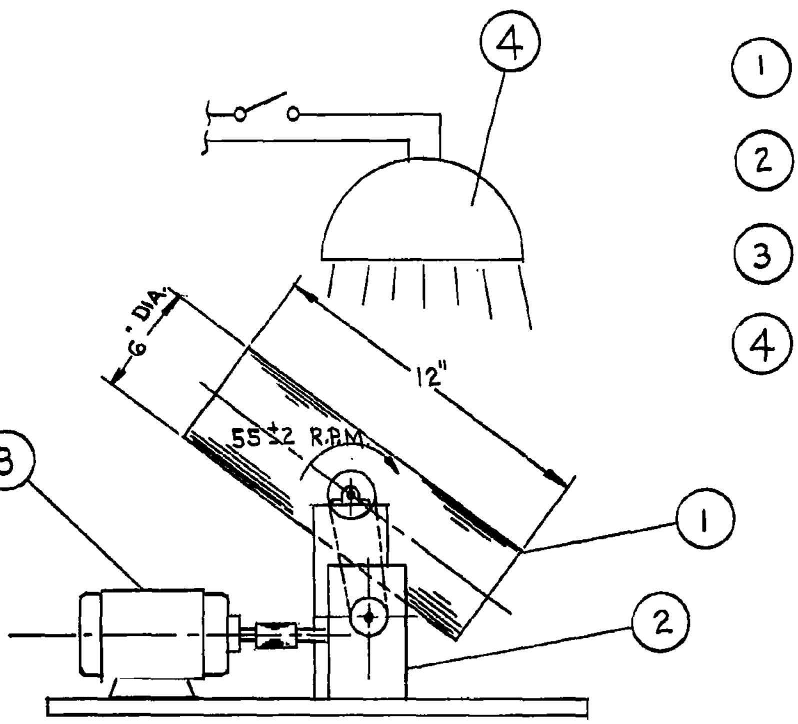
The specimen was then raveled to 1 inch in width by removing from each side approximately the same number of yarns. The specimen was then vertically attached to a holding beam on the upper side and to the load container on the lower side. The means of attachment were two clamps, measuring 1 inch by 1 1/2 inches. The long dimension was perpendicular to the application of load. The distance between clamps was 3 inches at the start of the test. Into the container attached to the lower end clamp, we poured water at a uniform rate until the specimen ruptured. The weight of the container and its contents was then reported as the apparent breaking strength of the fabric. The breaking strength of uncleaned fabrics was



1 Trough

2 Inclined Plane

Fig. 3. ABRASION APPARATUS



1 Tumbler

2 Gear Box

3 Drive

4 Infrared Heater with Reflector

Fig. 4. WASHFASTNESS TESTING APPARATUS

known. This information was made available by the Owens-Corning Fiberglas Corporation and Exeter Manufacturing Company for Fiberglas, and for the synthetics, the breaking strength data were supplied by J.P.Stevens and Company, Inc. The breaking strength was then determined in the direction of the warp for a cleaned sample and for a metallized sample.

III RESULTS

A. Variation of Thermal Porosity with Thickness of Deposited Metal

The thermal porosity of a metallized substrate varies inversely with the thickness of the deposit, in the manner illustrated in Figure 6 for aluminum as deposited on Fiberglas Style 128* fabric. In the interest of more essential measurements, curves for other metals and fabrics were not developed since the shape of this relationship is typical. The variation in thermal porosity follows the increase in opacity as the thickness of metal increases.

The term "thickness" as used in this report refers to a value calculated by dividing volume resistivity for solid metal by the resistance of a square of metallized substrate. For woven or perforated substrates, this measurement was made on microscope slides which had been in place adjacent to each side of the substrate during metallizing. The thickness values derived by this formula are dependent to some extent on the type of substrate on which the deposit occurs, and are not absolute thicknesses in a dimensional sense, and cannot be obtained directly from a woven or perforated substrate. Figure 5 shows the thickness-resistance relationship for the four metals considered in this program.

*Style numbers used to identify Fiberglas fabrics are industry standards. The synthetic fabric numbers refer to J.P.Stevens and Company nomenclature.

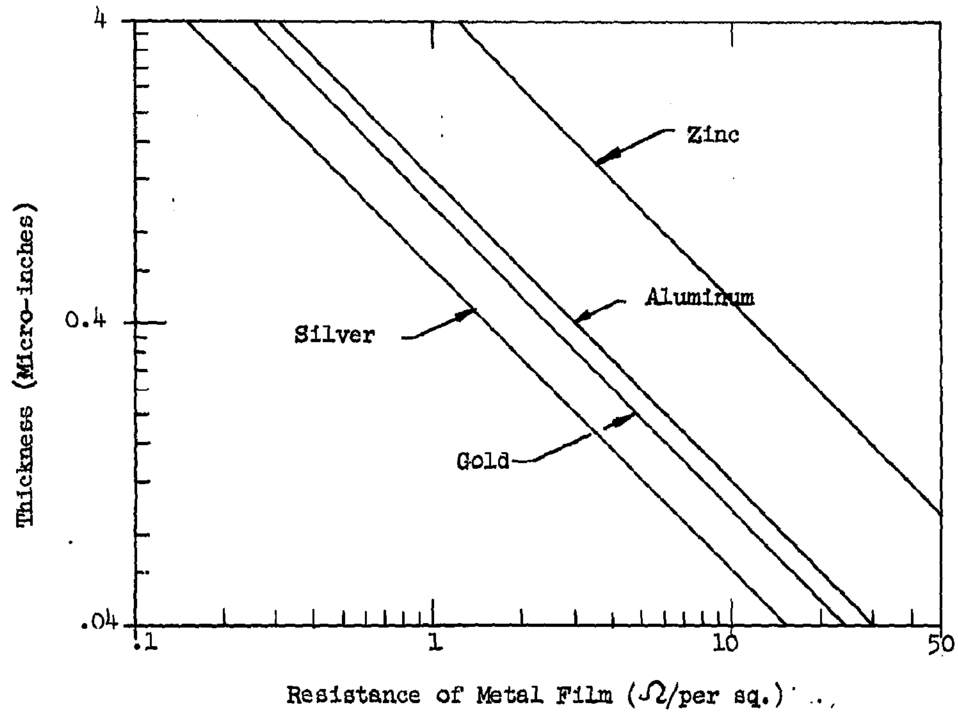


Fig. 5. RESISTANCE OF METAL FILM vs. THICKNESS

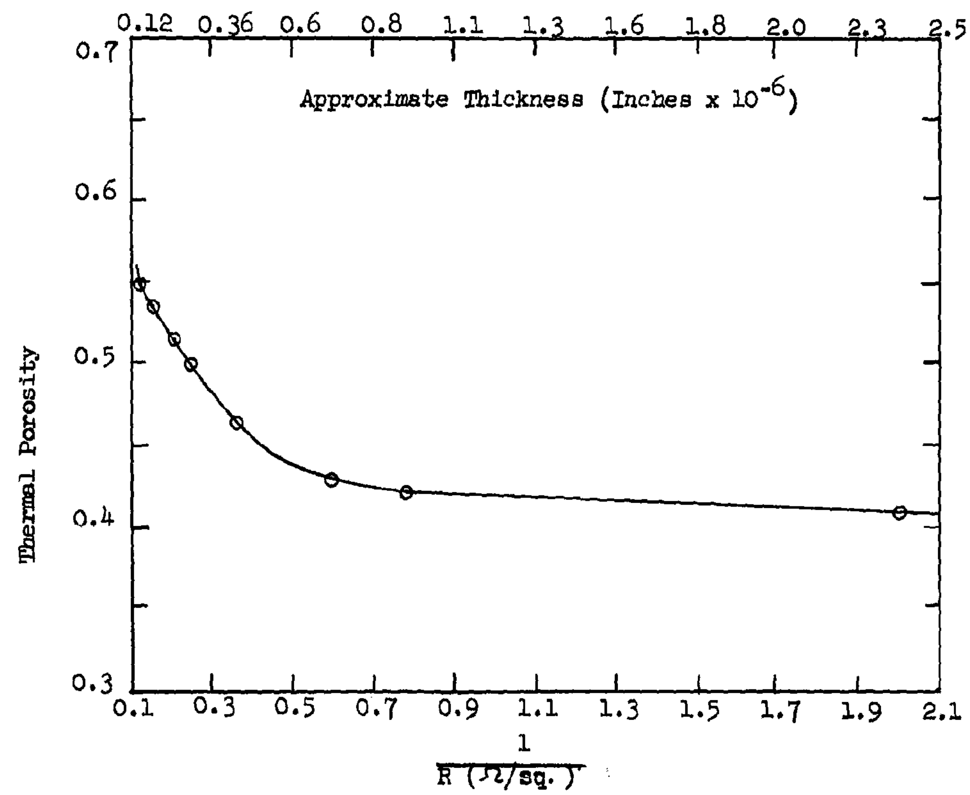


Fig. 6. THERMAL POROSITY vs. APPROXIMATE ALUMINUM LAYER THICKNESS

In all cases, metal deposits were kept in the 1 microinch range to insure adequate opacity. The transmissivities reported in the tables were measured on coated substrates using visible wavelengths and a Densichron. They represent direct transmission of light through open and lightly coated area, not through heavily coated surfaces, and vary with the type of weave.

B. Apparent Emissivity as a Function of Coating Metal

Zinc, aluminum, gold and silver were chosen as prospective metals because of their low emissivity in the infrared region of the wave spectrum. Fiberglas substrate (Style 116) was coated on one side with these metals and the resulting samples were sent to M.I.T. for low-temperature emissivity measurements. The resulting emissivities were:

Silver on Fiberglas	Style 116	0.28
Gold on Fiberglas	Style 116	0.31
Aluminum on Fiberglas	Style 116	0.33
Zinc on Fiberglas	Style 116	•0.37
Uncoated, heat cleaned Fiberglas	Style 116	0.84

C. Relationship Between Thermal Porosity and Emissivity

The thermal porosity apparatus was designed to permit comparative measurements rapidly. These measurements did not necessarily yield absolute values. In order to correct the data, it was necessary to establish how much the thermal porosity was in error as compared to the sum of emissivity and direct path transmittance. As a basis for this we have assumed:

$$\epsilon + \Upsilon + \sigma = TP \qquad (1)$$

Where:

ϵ = emissivity, or the fraction of energy absorbed and reradiated at a different wavelength

τ = transmittance, or fraction of energy transmitted at original wavelength, i.e., energy transmitted through the open areas in the fabric

σ = a constant by which the thermal porosity differs from the sum of transmittance and emissivity

TP = thermal porosity

also:

$$1 - (TP - \sigma) = r \qquad (2)$$

Where:

r = reflectance, or the fraction of energy reflected from the metallized substrate

therefore:

$$\epsilon + \tau + r = 1 \qquad (3)$$

Since we know emissivities of four coated substrates (the substrate being Fiberglas, Style 116) and can determine the transmittance with a Densichron, we can find the reflectance from (3) and σ from (2) as follows:

Metal	ϵ (%)	τ (%)	TP (%)	σ (%)
Zn	37	2	44	5
Au	31	2	38	5
Ag	28	2	35	5
Al	33	2	40	5

Tabulation in the Appendix (Table A-1) shows that σ does not vary by more than $\pm$ 0.5% for the four metals on the same substrate, and therefore may be considered largely independent of metal coating characteristics.

In subsequent measurements, we have assumed this correction in calculating reflectances, emissivities and thermal porosities. It appears likely that σ is an apparatus constant, dependent on such things as air convection and thermal leakage through thermocouple insulation. It also seems pertinent to suggest that this correction may vary to some extent with the reflectivity of the substrate, since energy reflected will in turn affect the total flux present in the region over the substrate. If this were the case, the correction would increase as an inverse function of the measured TP's but this is contradicted by the absence of high TP measurements for perforated Mylar. We have had occasion in past work to have a low temperature emissivity of 0.05 determined for unperforated Mylar metallized heavily with aluminum. The perforated material has an open area of 13%, giving an effective emissivity of 0.18. Using a transmissivity of 0.13 from Densichron measurements on the perforated sample, we expect a TP of 0.31. The measured TP was actually 0.289 (Table A-4).

If we base our TP determinations for substrates of undetermined emissivity on difference between the measurement for the unknown and the measurement for a substrate for which emissivity has been determined, we can avoid the correction for comparative purposes.

D. <u>Changes in Thermal Porosity with Varying Types of Weave</u>

<u>General</u>:

The thermal porosity of all fabrics, regardless of the type of weave, increased with the increase of the direct path transmission of heat energy.

<u>Plain Weaves</u>:

Seven Fiberglas styles of plain weave were tested. Fiberglas was chosen since its strands consist of equal numbers of monofilaments. The number of strands plied into a yarn has no direct influence on the thermal porosity of the coated substrate. Data show that the plain weaves are the best of the weave types investigated (See tabulation of results in Appendix, Table A-2a).

Crowfoot Satin Weaves:

This type of weave was investigated using four Fiberglas samples of different styles. Again the number of strands plied into a yarn does not contribute to a change in the thermal porosity of the fabric. The weave, however, influences the performance of the coated substrate. Data shows that the thermal porosity increases by about 6% as compared to the plain weaves. (See Table A-2b).

Plain Satin Weave:

This type of weave was represented by only one Fiberglas sample and the data obtained during investigation of this sample may therefore be inconclusive. It shows that this type of weave falls into the same group as crowfoot-satin types of weave. (See Table A-2c).

E. Coatings on Both Sides of the Substrate

This phase of the program was performed on two samples of each of the representative weaves, namely, Fiberglas, Style 116 and 125, representing the plain weave type, and Fiberglas, Style EX1052 and 138, which represented the crowfoot-satin weave type. The decrease in thermal porosity for the plain weave type was about 8%, while for the crowfoot-satin weave type, the improvement in the thermal porosity of the coated substrate was about 6%, as compared to their single side coated counterparts.

F. Multiple Layers of Coated Film on Single Side and Both Sides of the Fabric

The same styles and weaves as described in Result Section I were used in investigating the properties of substrates, coated on both sides with two layers of aluminum film. For investigating a two-layer film of aluminum on a substrate coated from one side only, a Fiberglas sample of plain weave, Style 116, was used. Double-layer coatings on both sides of the substrate do not bring about any improvement over single layers in the reflective properties of the substrate. (See Table A-3).

G. Aluminum Coatings on Substrates Other Than Fiberglas

This part of the investigation concerned synthetic fabrics and perforated plastic film. The synthetic fabrics were: Nylon 200, Nylon 300 and Dacron 5600. Nylon 200 was represented by two different types of weave; the others by one. The perforated plastic films were: one sample of perforated Mylar and one sample of perforated Saran. (See Table A-4).

1. Synthetic Fabrics

The three Nylon samples coated with a single layer of aluminum had a lower thermal porosity than Fiberglas having the same per cent of direct path transmission. This improvement in thermal porosity was of the order of about 3 to 7 per cent. The Dacron sample had a relatively high thermal porosity and also a high percentage of direct path transmission. Furthermore, when Dacron was subjected to thermal radiation, the sample which was furnished in the greige warped and deformed. A single aluminum layer on both sides of a synthetic fabric improved the thermal porosity over that recorded with the same samples coated on one side only. This improvement varied from 5% for Nylon 200 and Dacron 5600 to 12% for Nylon 300.

The thermal porosity of the unmetallized substrate material is not known; the uncoated fabric scorched and deformed when it was exposed to thermal radiation (See Table A-4).

2. Plastic Substrates

The perforated uniformly-coated substrates had the lowest thermal porosity of all substrates investigated. Two samples, perforated Mylar and perforated Saran foil, were aluminized and tested. The perforated Mylar showed a reflectivity of 77%, a value that can be improved mainly by reducing the area of perforation. The Saran sample scorched when exposed to thermal radiation. In this case, the source temperature was lowered and then the TP measured value was 34.1% which would indicate a reflectivity of 71%. (See Table A-4).

H. Results of Washfastness Tests

This phase of the program was performed in three stages. The first stage was a study of the dependence of washfastness on film thickness; the second stage was a study of the dependence of washfastness on substrate material and the last stage of the investigation was a study of the dependence of washfastness on the coating metal used. The data (Table A-5) shows that for the most part the washfastness is very low. The coating was practically removed after one wash cycle. Only in cases where thick films of aluminum metal were deposited, the fabric still retained some reflective properties. From the four metals tested, zinc adhered best. In terms of thermal porosity, this metal is not as satisfactory as others. Nylon 200, Style 30124, was the best substrate investigated. In all cases where aluminum still remained on the substrate, the decrease in thermal porosity varied from 10-20% after one wash cycle.

In the case where zinc coated substrate was tested for washfastness, it was observed that zinc remains physically present on the substrate. A Nylon 200, Style 30124 sample was first coated with zinc on both sides and then overcoated with a layer of aluminum on both sides. A washfastness test performed on this sample shows that aluminum was removed, and the zinc coating remained even after 2 cycles. (Since the sample scorched when a TP measurement was made, it is not shown in the table).

I. Results of Abrasion Tests

Our abrasion method failed to remove enough aluminum to cause a large change in thermal porosity. The thermal porosity fluctuated after each of the 25 abrasion cycles; in some cases, the reflective properties of the fabric actually improved. Metal removed came from the very top of each coated monofilament in the upper region of the yarn. Metal is diffused into the yarn among the monofilaments, or it remains at the sides of the yarn. The fluctuations leading to the decrease in thermal porosity are due to a burnishing effect of the aluminum film that came in contact with the abrasive. The net change in thermal porosity varied with the film thickness. For thick films, there is a larger burnishing effect than for thin films. The thermal porosity change varied also with the style of fabric, and generally, the thermal porosity increase varied from 0 to 5%. (See Table A-6).

J. Results of Breaking Strength Tests

Altogether 5 specimens of fabric were tested. The breaking strength was determined in the warp directions for cleaned and for metallized samples of fabric. The change in breaking strength is greater upon cleaning, which removes all softeners and binders from the yarns. Metallizing itself does not have a great effect on the breaking strength of the fabric. The net change in breaking strength varied, depending upon the fabric material and fabric construction. The results are reported in Table A-7.

IV CONCLUSIONS

On the basis of the results of the tests made, as tabulated in the Appendix and discussed previously in Section III (Results), the following conclusions may be drawn:

1. The limiting value of thermal porosity for aluminum-coated fabrics appears to be about 25%. Any subsequent improvement would come from using a metallizing process where the substrate would not be exposed at a normal angle to metal vapors, but where it would be exposed in such a way that the vapors would coat all of the surface of the yarn uniformly.

2. All substrates show a marked decrease in the breaking strength of the fabric after cleaning, an operation which removes oils and plasticizer films as a prerequisite to metallizing.

3. Abrasion tests indicate that wear does not materially decrease the efficiency of metallized fabric as a barrier to thermal radiation, since most effective abrasion takes place at the contact points only. The total amount of metal film removed is small.

4. Washfastness was improved, though not to a point where the efficiency of the fabric would not decrease appreciably when washed.

5. Metallizing both sides of a substrate decreases the thermal porosity of the substrate significantly.

6. The thermal porosity of a fabric decreases more than 5% when gold or silver metallizing is substituted for aluminum. A TP of 20% might be

attained by using a Nylon plain weave substrate having a very low per cent (less than 2%) of direct path transmission, coated with gold or silver on both sides. A TP as low as 10% might be gained by also premetallizing the yarn, or by using perforated plastic with 5% open area, coated on both sides with gold or silver.

7. Synthetic fabrics must be scoured and heat set before metallizing.

8. For minimum transmission of thermal radiation, our tests indicate that a fabric substrate intended for metallizing should have these characteristics:

(a) Low per cent of direct path transmission, (less than 2%)
(b) Fabric should be of the plain weave type
(c) Fabric should have a very high count in the warp and woof directions.

10. Nylons were most suitable of the fabric substrates metallized in view of thermal barrier performance obtained and their dense weaves and low weights.

V. RECOMMENDATIONS FOR FUTURE WORK

1. Increased Reflectance of Metallized Substrates

Further improvement in this area might be realized by an investigation of a coating method which would enable the metallizing of the yarn before weaving. In the fabric metallizing process, vapor is deposited at a normal angle of incidence to the vapor surface, thus coating the crown of the yarn and leaving the oblique sides of the yarn with a thinner film of metal. If the yarn were premetallized, an increase in the thermal efficiency of the fabric should be realized, especially under conditions of use where the fabric tends to work, rolling the yarn and exposing uncoated surfaces if the yarn is not completely coated. Such a process could probably be developed fairly quickly.

Gold or silver-coated fabric had heat reflective properties which were higher than those of an aluminum-coated fabric. Substitution of gold or silver for aluminum as a coating metal would further improve the thermal efficiency of the metallized fabric. Deterioration in performance with time on the shelf can be ascertained by periodic remeasurements.

The high count synthetic fabrics utilized during this program showed five or more per cent transmission. A more extensive survey of fabric suppliers might locate sources of high count fabrics having less than 2 per cent transmission. Such metallized fabrics would have an increased thermal efficiency over the fabrics so far tested.

2. Fabric Materials

In the course of the present program, the synthetic fabrics investigated were Nylon 200, Nylon 300 and Dacron 5600. An investigation of other synthetic fibers might yield a substrate which, upon cleaning, would retain more than 55% of its original breaking strength and which, upon metallizing, would have a better washfastness. Also, fabric woven from monofilaments or a substrate woven from flat strip yarns may improve the efficiency of a metal-coated substrate as a barrier to thermal heat radiation.

3. Perforated Plastic Substrates

This area offers great possibilities. In the present program, there was insufficient time to go very far in the direction of finding the best application of the results to commercially-available substrates. We tested perforated Saran and Mylar webs, with promising results. The Mylar is noisy, but otherwise is tough and fairly resistant to brief high thermal fluxes. The Saran is not noisy but is less tough and temperature resistant. Since their surface emissivities are about 0.05, direct improvement to a reflectivity of 90% can be expected merely by cutting the number of perforations to give 5% open area or less. This can certainly be arranged.

4. Washfastness

We were disappointed in the progress we were able to make in the direction of improved washfastness. Discounting changes in washing procedure as impractical from the standpoint of the Army, we were able to realize some improvement over early results by changes in coating technique. We feel that progress could be made through further work along the lines of finding an undercoat to which the metal coating would adhere more firmly.

5. Material for Trial in a Suit

We had promised to try to provide a few yards of a promising metallized substrate at the end of the program. This we were unable to do, partly because the final phases of the basic program proved more expensive than expected, and also because other expected continuous substrate metallizing did not materialize. This would have made a major undertaking out of setting up a machine to metallize one run on equipment otherwise idle. We suggest the advisability of selecting two or more most interesting substrates to be metallized together in a composite roll.

Table A-1 TOTAL LOW TEMPERATURE EMISSIVITY AND RELATED DATA

Emissivity Measurements Made at MIT with Source at Boiling Point of Water

Substrate Material	Weave Style	Sides Coated	Coating Metal	R $\Omega/\square$	% ϵ	% τ	% TP	% σ	% r
Fiberglas	116	single side	Zn	1.5	37	2	44.2	5.2	61.0
Fiberglas	116	single side	Ag	0.9	28	2	35.4	5.4	69.6
Fiberglas	116	single side	Au	0.9	31	2	38.3	5.3	67.0
Fiberglas	116	single side	Al	1.2	33	2	40.3	5.3	65.0
Fiberglas	116	uncoated	---	---	84	15	62.3	---	43.0

Table A-2a VARIATION IN TP FOR PLAIN WEAVE FIBERGLAS FABRIC

Fabric Style	Uncoated Fabric		Aluminum Coated Fabric					
	%TP	% T	R	%TP	% τ	% ϵ (calculated)	% r (calculated)
116	62.3	1.50	1.4	40.1	2.0	33.1	64.9
125	58.6	12.0	1.2	40.3	2.0	33.3	64.7
128	60.5	11.7	1.4	41.3	3.5	32.8	63.7
113	62.9	22.9	1.0	45.2	7.8	32.4	59.8
119	63.3	24.0	1.2	45.6	10.0	30.6	59.4
EM51	59.1	24.0	1.0	51.2	17.8	28.4	53.8
112	66.1	36.3	1.1	54.4	21.9	27.5	50.6

Table A-2b VARIATION IN TP FOR CROW-FOOT SATIN WEAVE FIBERGLAS FABRIC

Style	Uncoated Fabric		Al Coated Fabric				
	% TP	% τ	R $\Omega/\square$	% TP	% τ	% ϵ	% r
138	50.4	6.3	1.6	45.3	1.2	39.1	59.7
143	58.1	8.5	1.1	45.8	2.0	38.8	59.2
EX1052	61.5	11.5	1.1	46.5	2.2	39.3	58.5
120	66.6	11.7	1.1	47.3	2.6	39.7	57.7

Table A-2c VARIATION IN TP FOR PLAIN SATIN WEAVE FIBERGLAS FABRIC

Style	Uncoated Fabric		Al Coated Fabric				
	% TP	% τ	R $\Omega/\square$	% TP	% τ	% ϵ	% r
181	50.9	5.2	0.9	45.6	2.2	39.3	58.5

Table A-3 CHANGE IN TP FOR FIBERGLAS SUBSTRATE COATED WITH AL ON BOTH SIDES WITH SINGLE AND MULTIPLE LAYERS OF AL FILM

Style	Weave	One Side of Substrate Coated with Single Layer of Al				Both Sides of Substrate Coated with Single Layer of Al					Both Sides of Substrate Coated with Two Layers of Al					
		R Ω/□	%T	%TP	% r	Side N°	R Ω/□	%T	%TP	% r	Side N°	Layer N°	R Ω/□	%T	%TP	% r
116	plain	1.4	2.0	40.1	64.9	I	1.0	2.0	31.8	73.3	I	1	1.2	2.0	33.1	71.9
												2	0.9			
						II	1.0	2.0	31.8	73.3	II	1	1.0	2.0	32.1	72.9
												2	1.6			
125	plain	1.2	2.0	40.3	64.7	I	1.5	2.0	33.2	71.8	I	1	1.4	2.0	35.5	69.5
												2	1.8			
						II	1.3	2.0	34.4	72.0	II	1	1.3	2.0	33,3	71.7
												2	1.7			
138	Cr. sat.	1.6	1.2	45.3	59.7	I	1.2	1.0	39.3	65.8	I	1	1.4	1.0	39.9	65.1
												2	1.7			
						II	1.4	1.0	38.9	66.2	II	1	1.3	1.0	39.3	65.7
												2	1.4			
EX1052	Cr.Sat.	1.1	2.2	46.5	58.5	I	1.5	2.0	39.6	65.5	I	1	1.2	2.0	40.1	64.9
												2	1.6			
						II	1.5	2.0	38.3	65.8	II	1	1.3	2.0	40.1	64.9
												2	1.3			

Table A-4 SUMMARY OF TP MEASUREMENTS AND THE RELATED REFLECTIVITY FOR METALLIZED SYNTHETIC FABRICS AND PLASTICS

Material and Weave Type	Weave Style	Al Coating on One Side				Al Coating on Both Sides				
		R $\Omega/\square$	% T	% r	% TP	Side №	R $\Omega/\square$	% T	% r	% TP
NYLON 300 plain	34089	1.1	7.6	64.0	41.1	I	1.5	5.2	74.9	30.2
						II	1.15	5.2	76.2	28.9
NYLON 200 plain	30124	0.9	6.3	66.7	38.4	I	1.37	4.8	73.4	31.7
						II	1.36	4.8	73.8	31.3
NYLON 200 plain	30156	0.9	3.8	67.2	37.9	I	1.51	3.1	73.0	32.1
						II	1.51	3.1	73.0	32.1
DACRON 5600 plain	39307	1.0	26.3	48.2	56.9	I	1.0	22.4	54.5	50.6
						II	1.1	22.4	54.0	51.1
MYLAR perforated	---	1.4	13.0	76.2	28.9	---	---	---	---	----
						---	---	---	---	---
MYLAR plain	----	---	---	---	---	I	0.5	<1	>95	5.6
						II	0.5	<1	>95	5.6
SARAN perforated	----	0.9	12.0	70.9	34.1	---	---	---	---	---
						---	---	---	---	---

Table A-5

WASHFASTNESS AS A FUNCTION OF TP

Substrate Material	Weave Style	Coating Metal	R Ω/□	Before Wash % TP	1/2 Wash Cycle %TP	1 Wash Cycle %TP	2 Wash Cycles %TP
Fiberglas	128	Al on one side	1.7	45.6	47.6	56.2	----
Fiberglas	128	Al On one side	0.8	42.0	45.1	54.8	----
Fiberglas	128	Al on one side	0.5	41.8	43.8	52.3	----
Fiberglas	116	Gold on one side	0.7	31.4	---	no gold left	----
Fiberglas	116	Silver on one side	2.0	40.4	----	no silver left	----
Fiberglas	116	zinc on one side	1.75	38.5	----	58.4	----
Nylon 200	30124	Al on both sides	1.0	33.0	----	38.1	47.6
			0.8	28.5	----	35.3	47.3
Dacron 5600	39037	Al on both sides	1.0	51.1	----	61.0	----
			1.1	50.6	----	58.8	----
Nylon 200	30156	Al on both sides	1.5	32.1	----	50.3	----
			1.5	32.1	----	50.3	----
Nylon 300	34089	Al on both sides	1.5	30.2	----	45.1	----
			1.1	28.9	----	44.1	----
Nylon 200	30124	Al-Zn composite coatings on both sides	----	37.7	----	47.2	
			----	30.1	----	42.8	

Table A-6 CHANGE IN THERMAL POROSITY DUE TO ABRASION

Substrate Material	Weave Style	Coating Metal	R Ω/□	% TP Before Abrasion	Silica Sand Cycles 25 cycles % TP	Silica Sand Cycles 50 cycles % TP	Iron Grit Cycles 25 Cycles % TP	Iron Grit Cycles 50 Cycles % TP	Iron Grit Cycles 75 Cycles % TP	Net %Δ TP
Fiberglas	128	Al	10.0	54.9	47.7	---	56.2	56.8	---	+1.9
Fiberglas	128	Al	6.0	53.7	51.3	---	54.0	52.0	---	-1.7
Fiberglas	128	Al	4.5	52.3	49.3	---	50.9	51.5	----	-0.8
Fiberglas	128	Al	3.7	51.2	52.9	46.4	50.2	50.9	----	-0.3
Fiberglas	128	Al	2.5	47.0	45.1	45.2	53.6	51.1	----	+4.0
Fiberglas	128	Al	1.5	44.3	44.3	41.9	50.2	48.6	----	+4.3
Fiberglas	128	Al	1.3	42.5	43.1	44.2	48.6	46.2	----	+3.7
Fiberglas	128	Al	0.5	41.8	45.8	43.7	40.0	41.0	----	-0.8
Fiberglas	116	Ag	0.5	36.5	33.0	----	----	----	----	-3.5
Fiberglas	116	Zn	1.5	39.4	39.4	----	----	----	----	.0
Fiberglas	116	Au	2.0	36.3	35.9	----	----	-----	----	-0.4
Nylon 200	30124	Al	0.9	38.4	----	----	44.7	48.0	49.6	+11.2

Table A-7 CHANGE IN BREAKING STRENGTH OF FABRICS AFTER CLEANING AND AFTER METALLIZING IN VACUUM

Results of Ravel Specimen Test Method

Fabric Material	Fabric Style	Weave Type	Fabric Count		Breaking Strengths of Fabrics			
					Before Cleaning*		After Cleaning	After Metallizing
			Warp	Fill	Warp	Fill	Warp Only	Warp Only
NYLON 300	34089	plain	113	118	60.5 lb	62.5 lb	34.0 lb	35.9 lb
NYLON 200	30156	plain	101	70	121 lb	84 lb	59.1 lb	61.4 lb
NYLON 200	30124	plain	106	70	127 lb	84 lb	63.2 lb	58.3 lb
DACRON 5600	39307	plain	111	110	59 lb	64 lb	32.0 lb	35.1 lb
FIBERGLAS	128	plain	42	32	250 lb	200 lb	37.0 lb	44.2 lb

* Data for Fiberglas reported by Owens Corning Fiberglas Corporation and Exeter Manufacturing Company

Data for synthetic fabrics reported by J.P. Stevens and Company, Inc.

Table A-8

THERMAL POROSITY AS A FUNCTION OF COATING METAL

Coating Metal	R Ω/□	% T	% TP*	% r**
Al	1.4	2.0	40.1	64.9
Au	0.6	2.0	31.0	74.0
Au	0.7	2.0	31.4	73.6
Au	0.9	2.0	38.4	66.7
Au	2.0	2.0	36.3	68.7
Ag	0.5	2.0	36.5	68.5
Ag	0.9	2.0	35.4	69.6
Ag	1.4	2.0	39.6	65.4
Ag	2.0	2.0	40.4	64.6
Zn	1.5	2.0	39.4	65.6
Zn	1.5	2.0	44.2	60.8
Zn	1.75	2.0	38.5	66.5
Zn	2.0	2.0	41.0	64.0
Zn	3.0	2.0	39.8	64.6

* % TP as measured

** % r corrected for apparatus constant